QUANTITATIVE SIDE-SCAN SONAR RESEARCH FOR SEDIMENT CHARACTERIZATION

AND

DEVELOPMENT OF MULTIBEAM SUBBOTTOM PROFILER

Final Report

Award Numbers:
N00014-03-1-0318 and N00014-05-1-0750

OFFICE OF NAVAL RESEARCH

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Jerald W. Caruthers
Department of Marine Science
The University of Southern Mississippi
Stennis Space Center, Mississippi 39529

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PREFACE

This final report covers two tasks funded and conducted consecutively under Award Number N00014-03-1-0318: The first, funded at $200,000, covered the Fiscal Years 2003 and 2004 and the second, at $150,000 covered the Fiscal Years 2005, 2006, and 2007. A significant amount of the final reporting involved documents and presentations that continued into FY08 and FY09. This research was sponsored by ONR Ocean Acoustics Program, Code 321OA. Additionally, Code 321OA managed our third task which was for the development and construction of a multibeam subbottom profiler under Award Number N00014-05-1-0750 funded at $150,000 by the DOD Defense Universities Research Instrumentation Program (DURIP). This report covers both awards since all the activities of the principal investigator for the DURIP effort were funded and managed under the primary ONR award.

The long-term goals of this work are to contribute to the understanding of bottom backscatter at high frequencies, provide techniques for determining sediment characteristics based on backscatter, and to support ONR-sponsored seafloor scattering experiments. Two small ocean-acoustic research topics beyond those primary goals – oceanic bubbles and ocean acoustic tomography – are also discussed.

The narrative here is in the form of an Executive Summary. The details of the reported work are in the published documents and presentations that resulted and refereneed here. Those documents and presentations are listed at the end as a bibliography including some specifically referred to in this summary. The three main topical areas, which correspond mainly to the three tasks above, are A) seafloor characterization for the KauaiEx experiment, B) seafloor characterization for SAX04, and C) the construction of the MSBP. Ancillary small efforts conducted by the principal investigator included discussions on D) oceanic bubbles and E) ocean acoustic tomography in the Gulf of Mexico. Additionally, comments are made with regard to work conducted jointly with the Naval Oceanographic Office as our continued effort in seafloor and subbottom characterizations using and expanding our expertise and equipment development for future ONR work.

A Master of Science degree and a Doctor of Philosophy degree resulted from this work.

Jerald W. Caruthers, Professor
Department of Marine Science
University of Southern Mississippi
Stennis Space Center, MS 39529
Jerald.Caruthers@usm.edu
228-688-7126

EXECUTIVE SUMMARY

Introduction

Under an advanced-development project sponsored by the Space and Naval Warfare Command (SPAWAR), Award Number N00039-01-1-2217, and as a part of The University of Southern Mississippi Hydrographic Research Initiative, we specified and contracted for a specially modified side-scan sonar to produce quantitative, research quality, high-resolution data. The sonar operated at the dual frequencies of 150 and 300 kHz, and sampled the full waveform at 1 MHz and 12 bits for both frequencies and both sides. The sampling was done straight out of the sonar towfish by a separate digitizing processor without any pre-processing (Fig. 1), while the standard side-scan processor continued its normal processing to produce the usual ancillary data and images. A comparison of the processed digital data versus the standard side-scan image is shown in Fig. 2.

The results discussed in this report are from the processed digital waveform data, and some of the references discussed provide a detailed comparison of the results of such processing with analyses of standard side-scan sonar digital tiff.

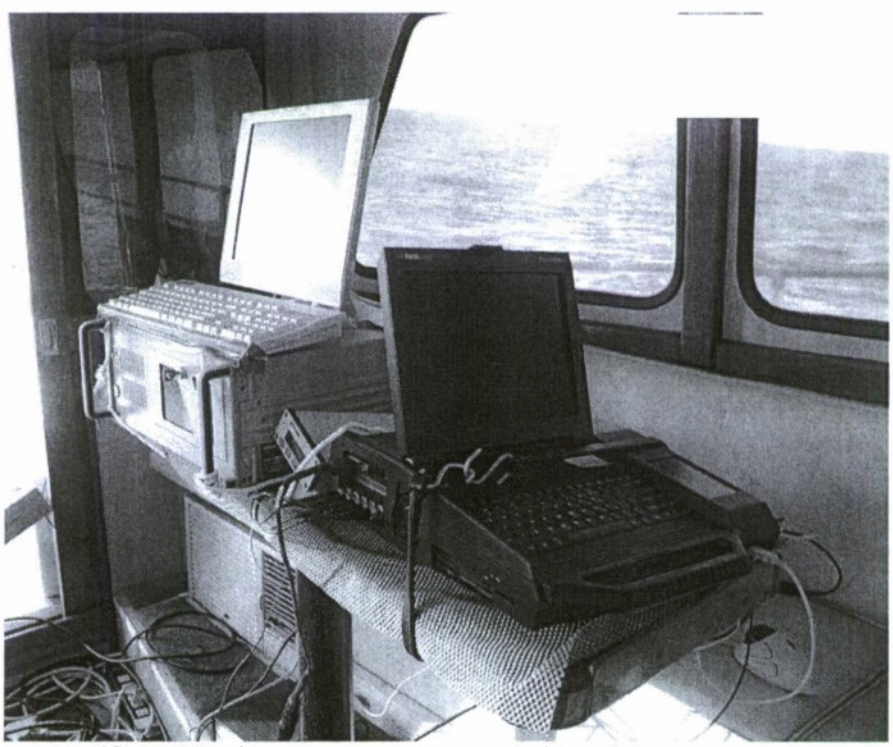

Figure 1: Modified MSTL side-scan sonar processor. The black field computer is the standard MSTL Processor, producing 8-bit tiffs, modified to feed raw, front-end data to the white computer for high-speed (1 MHz/channel), 12-bit digitizer for full waveform digitizing.

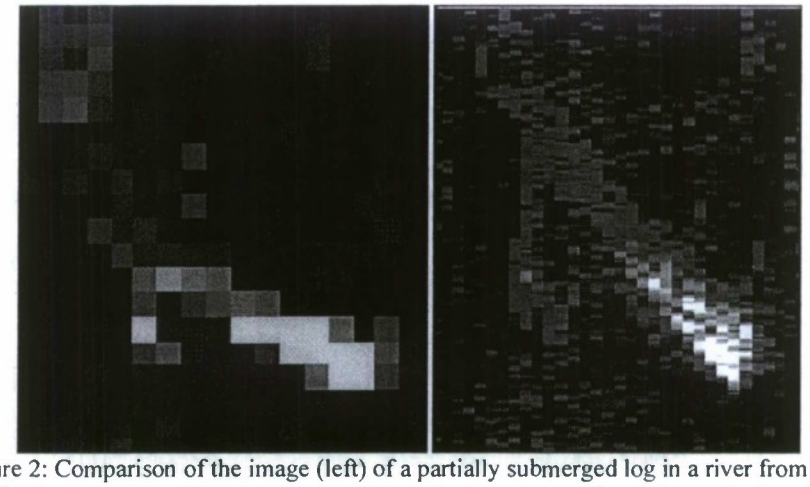

Figure 2: Comparison of the image (left) of a partially submerged log in a river from the standard processor and the quantitative 12-bit digital output of the digitizer displayed as a tiff image (right) . The higher resolutions in both bits and spatial scales are clearly apparent.

Discussion of Task Efforts

A. KauaiEx Support

The principal objective of this work was to support the High-Frequency Channel-Characterization Experiment (HFX, also known as KauaiEx). KauaiEx was conducted off the NW coast of Kauai, HI, at the 100-m contour, and had overall objectives of understanding the impact of bottom interactions in shallow water on underwater communications and on tomographic reconstructions for shallow-water environments. The specific tasks of the project reported herein were to provide wide-area, high-resolution data to describe the fine-scale nature of the seafloor and to develop a means of classifying bottom characteristics based on high-frequency backscatter signals for use by the other KauaiEx experiments. These goals require an understanding of the statistical nature of the backscatter signal and how to delineate changes in the bottom based on changes in the statistics of backscatter.

The plan was to conduct three days of surveys with transverse swaths along 7-km paths centered on the 100-m depth contour. High winds and heavy seas prevented surveying for the first two days. This was somewhat expected and was factored into our survey plan. The final day we conducted two transits along the 7-km track. This actually produced sufficient results for our purposes.

While not of direct value to the specific objectives of KauaiEx, on the second day we took advantage of the available time and resources to conduct a survey in a 35-m depth, more sheltered area. This did, however, provide useful results for the long-term objectives of our ONR projects.

The initial report on this work can be found in Ref. A1. Subsequent papers and presentations are given in Refs. A2 to A5. In summary, we conclude that there was a ubiquitous field of nearly sinusoidal sand ripples produced by what was an apparently gentle flow across the shelf near the 100-m contour (Fig. 3). The ripples were statistically variable with a mean wavelength of slightly over 1 m and trough-to-crest heights of about 5 cm. Interspersed in this field seemed to be globular-like inhomogeneities with a scale

near 3 m. (These may simply be regions where the sand ripples were washed out.) At the southeastern end of the track and out at a range of about 100 m there appears to be some more rugged ridges. Although the primary KauaiEx experiments centered on frequencies from a few kilohertz to a few tens of kilohertz propagating generally along the 7-km paths, bottom interaction occurring along the parallel ripple crests and troughs as determined by our higher frequencies could certainly have influenced the lower-frequency path characteristics. This HF work produced the only KauaiEx data capable of resolving this fine-scale at 100-m depths.

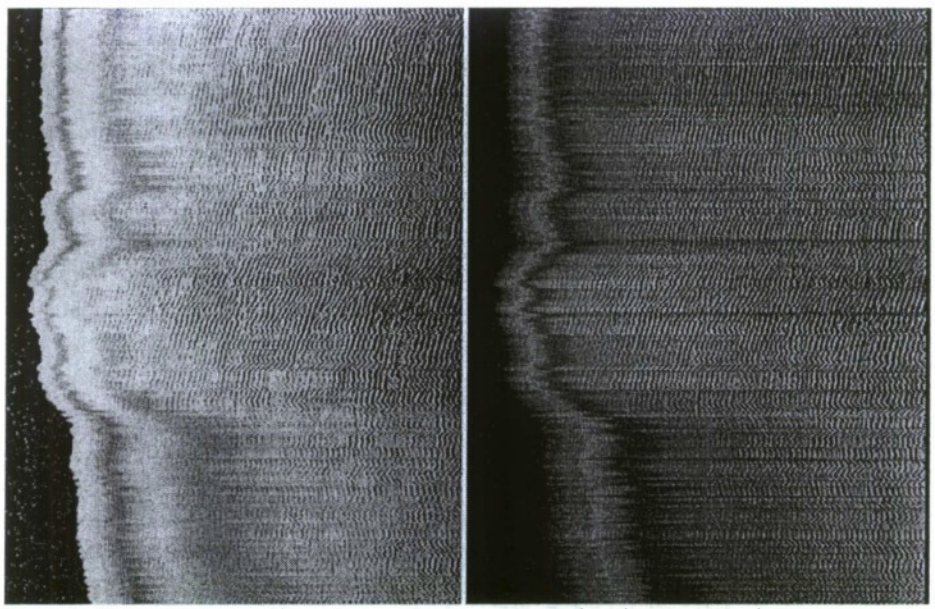

Figure 3: Side-scan image (from the standard processor) showing the ubiquitous sand-ripple field in the KauaiEx region. Left image is for 150-kHz backscatter and right image is for 300 kHz.

B. SAX04 Support

The objectives of this work were to collect quantitative, calibrated, side-scan-sonar data in support of the ONR SAX04 shallow-water, seafloor scattering experiments and to conduct additional seabed backscattering experiments and surveys in conjunction with other ONR projects such as the Ripples DRI. Based on data collected off Ft. Walton Beach, Florida, we (1) supported analyses conducted in ONR projects that may require a wide-area, quantitative description of the seafloor in regions of planned experiments, (2) determined the applicability of various scattering models to describe the data, (3) developed and applied algorithms for determining change boundaries in the seafloor scattering regimes, and (4) connected this basic research effort with a Naval Oceanographic Office, Mine Warfare Program, advanced-development effort for the investigation of techniques for processing and archiving high-resolution, side-scan sonar data and for automated seafloor classification based on a joint NAVO/USM survey off Orange Beach, Alabama.

The principal contribution to the primary task was presented at the SAX04 meeting New Orleans in March, 2006 (Ref. B1). The PI demonstrated at the meeting that, at the time of our survey, there were marked differences between the seafloor surface

character as represented by the probability density functions (PDFs) for the 300-kHz data, and clearly visible in the standard images (e.g., Fig. 4) for two different passes of the region, for the 60 x 60 m designated primary area and area to the NE where the ship was later moored to conduct the detailed lower-frequency, bottom-interaction experiments.

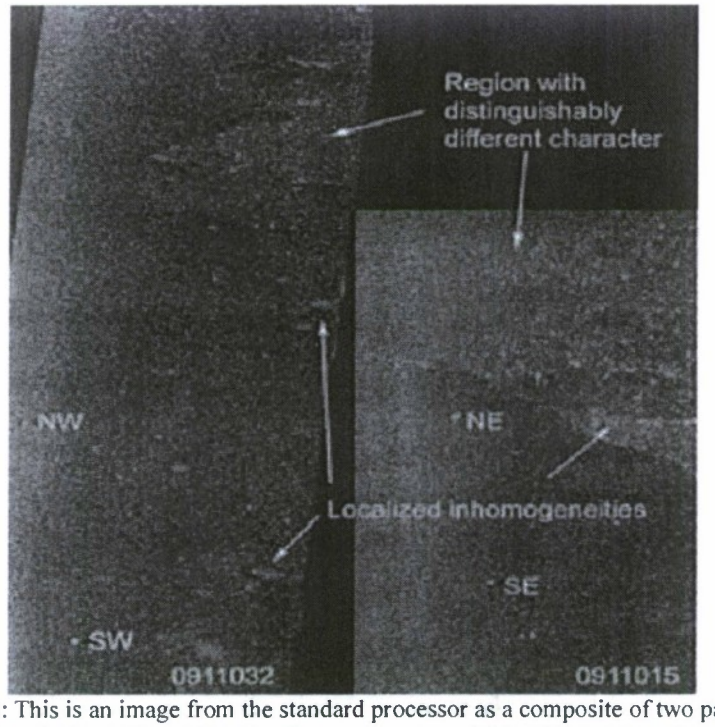

Figure 4: This is an image from the standard processor as a composite of two passes (files 0911032 and 0911015) at 300 kHz. The markers (e.g., NE) delineate the primary region of the experiment. Some experiments were performed in the area NE of that block.

Figure 5 shows, in greater detail and for a different pass, an image of the high-resolution digital data at 300 kHz for a region right at the seafloor-change boundary. Figure 6 shows the marked difference in the PDFs on the north and south sides of the change boundary at 300 kHz and no discernable difference at 150 kHz. This may suggest that there are some very small, hard objects (possible shell bits) of the order of a few millimeters that strongly influence the backscattering at the higher frequency.

Since the enhanced backscatter at 300 kHz is not observed at 150 kHz it is not likely to impact scattering at the even lower primary-experiment frequencies. Moreover, it probably turns out to be a mute point since between the times of our measurements and the primary experiments, Hurricane Ivan past through the area and certainly altered the bottom to 10 or more centimeters.

The general results overall are discussed in Refs. B2 to B5. These additional results deal with technical aspects and developments concerning optimal analyses of wide-area, high-resolution data and processing. The point of such analyses is to suggest that in any experiment involving bottom interactions in any frequency range, a component of the experiments should require a detailed wide-area, high-frequency survey

and analysis to provide high-resolution characteristics of the bottom and regional changes.

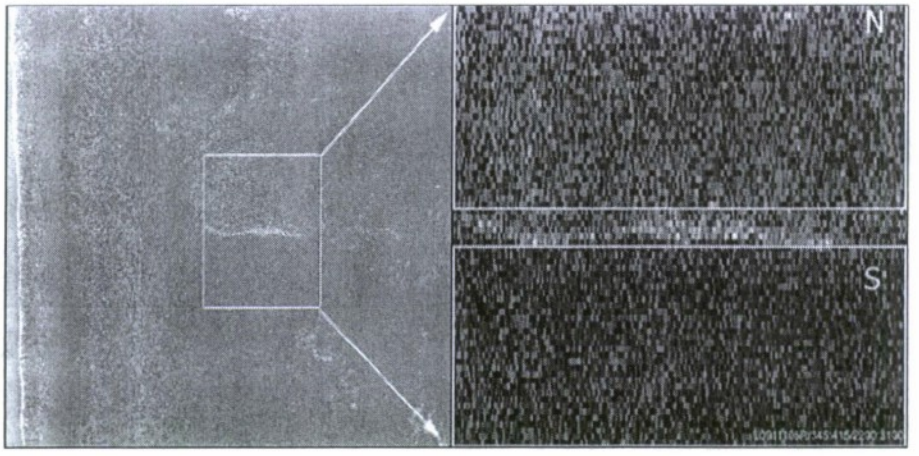

Figure 5: Shows the change boundary for file 0911105 on the left and an expanded view on the right.

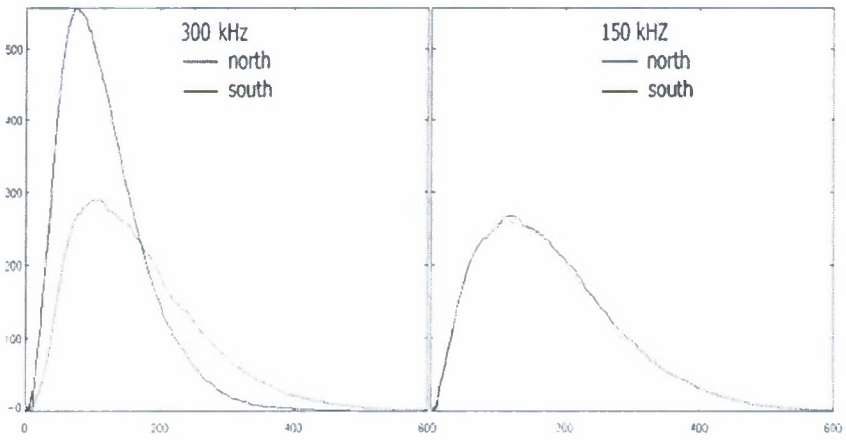

Figure 6: Shows the changes in the PDFs between the northern and southern regions for the two acoustic frequencies of 300 and 150 kHz.

The conclusions of this work led to a project for the Naval Oceanography Office, Mine Warfare Program, that resulted in recommendations for changes in the way NAVO collects, processes, and archives its digital data. Although much of the original analyses for such digital techniques were developed in this ONR project, they were fine tuned in the additional effort made for NAVO. Further details of this can be found in the NAVO report on the analysis of data collected in a joint NAVO/USM survey at Orange Beach, Alabama, which is summarized in Ref. B6. Reference B7 is an extended abstract and presentation demonstrating a new geometric theorem that, under specified conditions, can provide an estimate the amplitude of sand ripples from a remotely sensed seafloor.

Much of the research in this SAX04 project led to the Master of Science degree for Ms. Vidya Renganathan.

C. Multibeam SubBottom Profiler:

A Multibeam SubBottom Profiler (MSBP) was constructed with funding from the Defense University Research Instrumentation Program (DURIP) managed by the Office of Naval Research. DURIP/ONR provide funding for hardware, materials, and a contracted effort to build the instrument's electronic/digital components. A USM marine technician designed and assembled the structural components. The activities of the PI were funded by the ONR grant as previously mentioned. After the system was completed, the Naval Oceanographic Office provided funding for a partial test of the assembled system in a local river. Figure 7 shows the final assembled MSBP.

The primary acoustical and structural hardware for the MSBP are three T70 Neptune Sonar transducer modules set end-to-end in a line. Each T70 has five 11.5-kHz elements in each of two parallel lines. The resulting system is composed of fifteen elements in each line with a total length of 1.3 m. The two parallel lines are separated by about 8.5 cm (approximately ½ a wavelength). Each line has a full beamwidth to the 3-dB points of about 5 x 70 degrees, down track versus cross track, respectively. The full waveform from each of the two lines is digitized in two pressure vessels attached at the end of the line of transducers. The system is then designed to have a narrow-beam scan to each side like a side-scanning sonar, except that the data are three dimensional based on interferometric or correlation processing between the lines.

The MSBP was presented in Refs. C1 and C2. A presentation was also made to NAVO (Ref. C3). That presentation resulted in NAVO funding for testing the MSBP. This approach to NAVO was initiated because NAVO had recently procured several large Sinrad EM120, 12 kHz, multibeam system for its larger survey ships. That Sinrad system has a new augmentation of software called the SBP120 that allows for the EM120 data to be used for multibeam subbottom profiling. The USM/MSBP, although also operating at 12 kHz, is smaller, in part by virtue of its interferometric technology, and can be used for surveying in shallower water and as a trainer for NAVO's larger, deep-water systems. The system can also be used for buried mine-hunting in shallow water.

D. Oceanic Bubbles

References D1 to D4 are research efforts conducted primarily with Dr. Ralph Goodman and researchers at the Naval Research Laboratory. The work with Dr. Goodman centered on continued development of theory and the analysis of the ONR/NRL Scripps Pier Experiment 1997 (SPEx97) data with particular regard to signal dispersion. One of the efforts (Ref. D3) was for theoretical development of higher-order inversion (HOI) of attenuation data that had been developed to first-order inversion (FOI) by the PI while at NRL. Just as had been done for the FOI, the HOI was demonstrated with data taken at the SPEx97. The PI was the principal co-chair of a special session for the memory of Dr. Ralph Goodman at the Portland meeting of the Acoustical Society of America in May of 2009.

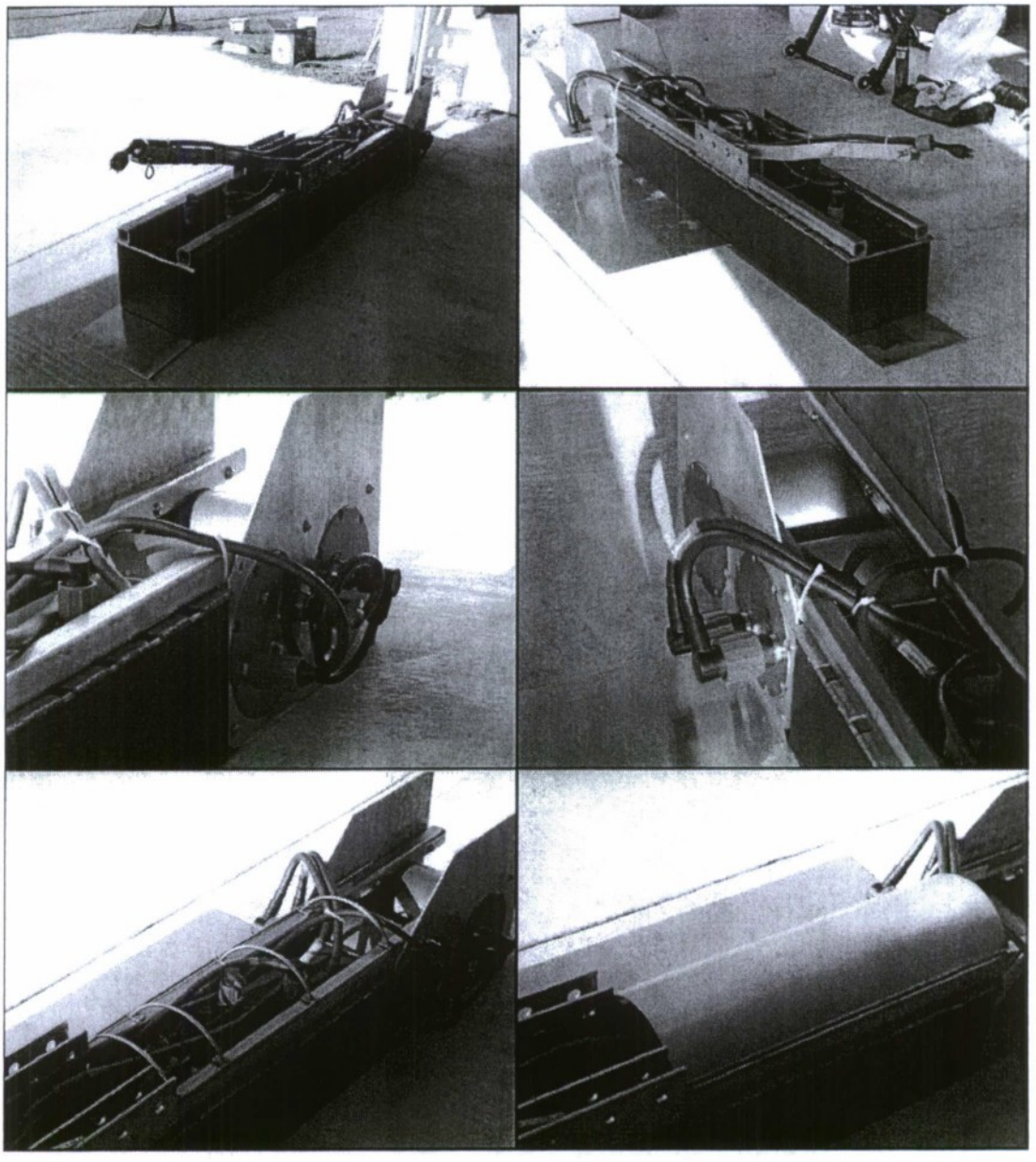

Figure 7: The Multibeam SubBottom Profiler

E. Ocean Acoustic Tomography

While at NRL, from which the PI retired in 2000, an effort was initiated by the PI for ocean acoustic tomography in the Eastern Gulf of Mexico for the deep-water monitoring of the GOM loop current. That effort was continued at USM with several papers and presentations (Refs. E1 to E6), and a wide range of collaboration. Most of that work was conducted with colleagues at the University of New Orleans (UNO) and the University of Louisiana in Lafayette, Louisiana (ULL). This work lead to a PhD for Sergey Vinogradov working under the PI. References E1 to E3 are invited presentations

and proceeding papers at the World Conference on Systemics, Cybernetics and Informatics in 2005. The PI was the principal co-chair for that session.

Acknowledgements

The author expresses his appreciation for the support of ONR program managers Drs. Jeffrey Simmen, Ellen Livingston, and Robert Headrick, Code 321OA; Project PI's Drs. Michael Porter, KauaiEx, and Eric Thorsos, SAX04; and colleagues Drs. Ralph Goodman, USM, Steve Stanic, NRL, and Natalia Sidorovskaia, ULL, and George Ioup, UNO, Roger Meredith, NAVO . The author is indebted to the USM marine technicians, Richard Slaughter and Erik Quiroz for survey and mechanical support.

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Department of Marine Science
University of Southern Mississippi
Stennis Space Center, MS 39529

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14. ABSTRACT
This report discusses research on seafloor backscatter at high frequencies in the range of a few hundred kilohertz using a specially modified side-scan sonar producing high-fidelity, high spatial- and bit-resolutions, quantitative acoustic-waveform data. A part of the work under N00014-03-1-0318 supported PI's effort in constructing the Multibeam Subbottom Profile under N00014-05-1-0750.

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